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A Contract Study

West European Aerospace Composites

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GI C 87-10070
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A Contract Study

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West European Aerospace Composites

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Summary

Information available as of 1 September 1987 was used in this report.

The United Kingdom, West Germany, and France are committed at both the government and corporate levels to developing a competitive composite aerospace production capability by 1990. The major aerospace firms in those countries—Dassault, Aerospatiale, British Aerospace, and Messerschmidt-Bolkow-Blohm (MBB)—have already acquired capital, equipment, and space for major composite facilities. All three countries have developed their technical expertise in automated production in the last eight to 10 years.

Several factors have enabled the leading companies to put their research knowledge into production. All three governments have committed capital and personnel to developing a commercial and military composite aerospace capability and have continually provided the aerospace companies with production aircraft contracts. These contracts, such as the A300, A310, Tornado, ATR 42, ATR 72, EAP, and Rafale, have provided sufficient numbers of aircraft with advanced technology to make the use of large, automated composite layup and cure equipment cost effective.

Current production and design methods tend to use well-tested and safe materials. The European aircraft all use carbon/epoxy layups that are well understood and easy to work with, compared with the new thermoplastic materials. Automated equipment is available both from US and West European manufacturers. The designs tend to follow conventional material strategies, thereby leading to excessive weight and safety factors. The aerospace companies are beginning to use new forms of carbon fiber reinforced plastic (CFRP), such as poly ether ether ketone (PEEK)/carbon, and to develop manufacturing techniques for automated production. Currently, Imperial Chemical Industries—a British company—the maker of PEEK, knows the most about production technologies, but dissemination of information to customers will rapidly spread production knowledge. Aerospatiale, MBB, the Plastics Institute in Aachen, BASF, and Westland are known to be researching PEEK and other thermoplastic resins.

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Declassified in Part - Sanitized Copy Approved for Release 2011/11/15 : CIA-RDP88T00706R000400370002-9

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Scope Note

This study, prepared under contract for the Office of Global Issues, outlines the general development of the carbon fiber composite aerospace industry in Western Europe in order to give a perspective of past developments and to provide a background on which to base projections of future developments. The text is broken into three major sections on the United Kingdom, West Germany, and France. Conclusions are presented on the current level of European composite capability and future developments for the aircraft industry. The main material of interest is carbon fiber reinforced plastic, but carbon/carbon composite is also covered under the discussion of France.

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West European Aerospace Composites

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The United Kingdom, Germany, and France are committed to developing a competitive composite aerospace production capability by 1990. Major aerospace firms have already acquired capital, equipment, and space for facilities and are planning to continue growth in machine acquisitions and product sophistication. Current production and design methods tend to use well-tested and safe materials that are thoroughly understood and easy to work with, although the companies are beginning to use new forms of carbon fiber reinforced plastic (CFRP) and to research poly ether ether ketone (PEEK) and other thermoplastic resins.

United Kingdom

CFRP Aircraft Structures

The United Kingdom was the first European country to begin earnest development of CFRP aircraft structures. This was due in large part to the development of carbon fibers (CF) by the firm Courtaulds, which developed a polyacrylonitrile (PAN) fiber in the early 1960s. By the early 1970s, Courtaulds had become one of the largest CF producers. The United Kingdom had a vested interest in keeping Courtaulds a leader, and therefore backed an early push to develop uses for CF.

The first developers of CFRP structures were the Royal Aircraft Establishment (RAE), the British Aerospace Company (BAe), and the Rolls-Royce Company. The RAE, the most progressive government lab to investigate composites, has contributed a great deal through research as well as through encouraging British corporations to use CF. BAe supported research but was slow to integrate CFRP into large structural components. Rolls-Royce had initial high hopes for CFRP turbine components and has invested much in the development of turbine blades and secondary turbine components.

The RAE has been involved in developing several production techniques. The main forming methods initially investigated were compression molding, filament winding, and tape laying. CF was over $100 per pound during the early 1970s, and the only way to make high-volume prodution of CFRP cost effective was to automate production techniques. 25X1

Researchers drew heavily on experience available from producers of glass reinforced plastic (GRP). The technology for producing GRP structures was well established by the early 1970s. Initial CFRP research was conducted with modified GRP equipment, but problems developed because of the physical properties of CF. 25X1 25X1

BAe recognized the potential of CFRP, but was slow to develop large-scale applications. It developed several CFRP components for its jets, but did not work that much with automated production techniques during the early years of development. The main point of early studies was to develop design techniques and to gather flight data. One of the first components developed was a rudder trim tab; the test components of the tab were made of carbon/epoxy. 25X1

BAe continued development of noncritical aircraft components such as spoilers, doors, trim tabs, and fairings. The earliest large component program was for the Tornado taileron, which was conducted jointly with Messerschmidt-Bolkow-Blohm (MBB) of West Germany. The project started in 1973 and continued through the early 1980s. Both BAe and MBB built test components, and both companies developed design and manufacturing techniques. By the late 1970s, the design for the taileron was well tested and a production contract was issued for CFRP tailerons on the last 400 Tornados built. This was the first large-scale production effort in CFRP for both companies. 25X1

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Composites Technology

The carbon fibers referred to in this paper are generally made from polyacrylonitrile (PAN) or pitch. These fibers are stiff and brittle compared with glass fibers, and dry fibers can be easily damaged during handling.

These fibers are combined with a matrix material to form a composite. The two most common types of matrix are thermoset and thermoplastic polymers. Fibers and matrix may be combined into sheets or rolls of tape to form prepreg (preimpregnated) materials. Thermoset prepregs generally use epoxy resins. These prepregs are tacky at room temperature and are referred to as being in the beta stage. Epoxies must be cured at elevated temperatures for several hours to harden the resin into the final product. The elevated temperature provides energy for the matrix to polymerize into a cross-linked network. Thermoplastic resins do not need to be cured because they cannot be cross-linked. Thermoplastic prepregs must be melted before they can be shaped or laminated together.

The easiest technique for laying up composite materials is hand layup. Tapes or sections of cloth are placed on top of one another at various angles prescribed by the designer. This technique is slow, but it is useful for highly complex parts and parts made only a few times. Hand layup has the added advantage of using a laborer who is constantly checking for defects both in ply orientation and the raw material.

Tape laying is an automated technique designed to replace hand layup. Modern tape-laying machines generally use large gantry-type robots to spread tape on a mold surface. The robot head will roll the tape out at a specified angle, cut the tape at the proper length, and move to the next position to lay down another strip. The main problem with tape laying is 25X1
that the fiber orientation must be controlled very precisely. Just a slight gap or overlap may cause a strength reduction of several percent. 25X1

Filament winding is an automated technique for making cylindrical parts. Tows of fibers—which may be prepreg or pulled through a resin bath—are wound onto a mandrel at specified angles. As with tape laying, winding requires precise control of the fiber orientation in order to prevent strength losses. 25X1

Filament winding is broken down into two categories. Helical winding refers to fibers being wound into a helical pattern onto a mandrel. Fiber angles generally vary from 90 to 10 degrees as measured from the axis of rotation. Polar winding refers to the capability of winding fibers at angles as small as zero degrees. 25X1
Polar winding is used to make structures with closed ends such as spherical pressure vessels. 25X1

The automated machines progressed rapidly after the mid-1970s because of the increasing power of small computers. Small digital controllers capable of handling complex instruction sequences and maintaining precise control made automated winders and tape layers less expensive, more reliable, and easier to control. 25X1

Rolls-Royce began experiments with CFRP turbine blades before 1970 and invested in automated presses for compression molding of prepreg materials. The company was convinced of the usefulness of CFRP and expanded into other products. Unfortunately, the high cost of CF in the early 1970s made the products too expensive for most customers. In one instance, Rolls-Royce sold CFRP aircraft cabin flooring to the British Overseas Airways Corp. (BOAC). Not more than two years later, BOAC had concluded that aluminum flooring was more cost efficient and returned to the original floor design. The financial problems that beset Rolls-Royce in the 1970s also hindered development. [redacted]

Rolls also had problems in developing its turbine components. The brittle fibers led to production problems that were overcome, but the use of CFRP in the high-temperature regions of the engines proved to be elusive. The impact strength of CFRP turbine blades was also a problem. CFRP blades shattered when hit by a bird, and many more CFRP blades were damaged by birds than were conventional metal blades. Today several engine components in the cooler regions of the engine are CFRP, but the high-temperature components are still metal. In 1984 Alan Thompson of Rolls-Royce published a paper illustrating the use of CFRP in turbine engines. The types of parts mentioned include cooling fan blades, ducts, engine casings, compressor blade assemblies, gas generator and radial drive fairings on the RB211, and forward thrust reversor doors. Compression molding is used to produce most parts for Rolls-Royce. [redacted]

With the increasing research came an increase in education and research in CFRP at the university level. The United Kingdom was probably the most successful European country in composite education in the early 1970s. Periodicals show that there was an early call by researchers for university research and education programs, increased development of production components, and increasingly active society meetings such as SAMPE and the Plastics Institute.

[redacted]

With ever-increasing awareness in CFRP, several more companies began investigating the development of aircraft components. Bristol Aerojet began working with composites for filament-wound rocket motor cases in conjunction with Imperial Metal Industries and Weston Super-Mare in 1971. Hawker began research in aircraft composites about the same time. Other British firms that climbed on the composites bandwagon to develop filament winding were Redland Pipes, Imperial Chemical Industries (ICI), and Ciba-Geigy UK. [redacted] 25X1

Bristol Aerojet began producing production components soon after entering the market. Bristol designed 25X1 and built the first polar-wound rocket casing in 1972 and continued to develop filament-wound components throughout the 1970s. [redacted] 25X1

ICI and Ciba-Geigy developed their composite interests through resins. Both firms worked with epoxies and polyimides. To promote their products, both companies also worked on automated manufacturing 25X1 methods such as filament winding and tape laying. Both firms have grown into major suppliers of resin systems in the aerospace composites industry. [redacted]

Throughout the early years of CFRP, the main production method was hand layup because CFRP materials were still extremely high priced. Manufacturers were unsure of failure characteristics and only worked with small parts in test programs. The most advanced automated technique was filament winding because of its development through mass production 25X1 of GRP. [redacted] 25X1

Filament winding was fast becoming the accepted means of manufacturing pressure vessels and pipe. This early advancement was due mainly to the experience of GRP pipe manufacturers. Helicopter rotor blades were also beginning to be manufactured by filament winding, but most airframe components could not be wound because of the configuration. [redacted]

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Another technique being refined for mass production was tape laying. The United Kingdom lagged the United States in technology, but gained valuable experience in the early 1970s working with GRP on naval ship construction. [redacted]

In the mid-1970s the prices for CF began to drop. Lower prices in conjunction with improved confidence in design and failure analysis and improved layup techniques prompted the United Kingdom to invest in research of large aircraft structures. The United States had already built rudders, panels, spoilers, and air brakes out of CFRP and boron/epoxy. The United Kingdom [redacted] responded with a primary structures program sponsored by the Ministry of Defense. [redacted]

The primary structures program was carried out by BAe. A new wing using CFRP skins and spar caps was developed for the Jaguar. The wing was to be constructed in 1981, but MOD spending cuts slowed progress. An engine bay door for the Jaguar was also built out of CFRP in conjunction with Grumman Aerospace in the United States. Another major project was to design and build a CFRP front fuselage/cockpit that was developed with integral stiffeners and bonded components. These programs expanded on the knowledge gained from the Tornado taileron program. [redacted]

In addition to the structures projects, BAe also invested in research on design and failure of composites. The major projects were concerned with fatigue and damage, variability and lifetime, and defects and repairability. Some of this work was subcontracted to Grumman. [redacted]

In conjunction with these projects, BAe set up a composites task force in 1980 with the Warton facility as the lead division. This meant that all composites development had to be conducted under the supervision of Warton. A 10-year program was initiated to provide BAe with the facilities and knowledge to be competitive in the 1990s. Much of this development was funded privately in the face of continuing government cutbacks. [redacted]

A major part of this program is the development of a fully integrated composites layup and curing facility at Samlesbury, scheduled for completion about 1990. A 50,000-square-foot clean room was built with the capability to increase the size to 160,000 square feet. 25X1 Automated tape laying machines will lay up parts. A water jet cutter will cut the plies to the desired profile. The parts will then be automatically transferred to a computer-controlled autoclave. Robots will help transfer material and tools. Structures will be joined with adhesive bonding as well as with metal fasteners. New compression presses specifically designed for composites by Murdoch, Inc. in the United States will 25X6 mold some of the components. A central computer 25X6 will control the entire facility (see figure 1). [redacted] 25X1

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PEEK

A recent development of importance in materials in ICI's prepreg material is based on the thermoplastic resin PEEK. PEEK is a thermoplastic, not a thermoset like epoxies. The main advantage of PEEK is its ability to be formed by simply raising the temperature above the melting point (334° Celsius). No cure time is required, and the material can be melted and formed repeatedly. The material is as strong as epoxies and tougher. The resin does not deteriorate, and the 334° Celsius melting point means the material can be used for most aircraft structures except high-temperature parts such as supersonic leading 25X1 edges. Every major military manufacturer in Europe and the United States has begun development of PEEK/carbon structures. The main problems to date have been temperatures required to form the plastic and the limited experience of the manufacturers with thermoplastics. The high temperatures required for forming the material mean energy costs are high and 25X1 worker safety becomes more difficult and costly. [redacted] 25X1

Thermoplastics present problems for manufacturing because they are not sticky like thermoset resins at room temperature. Thermoset composites are layed up with the resin in the beta stage, when the resin is slightly tacky and pliable because it has not yet been

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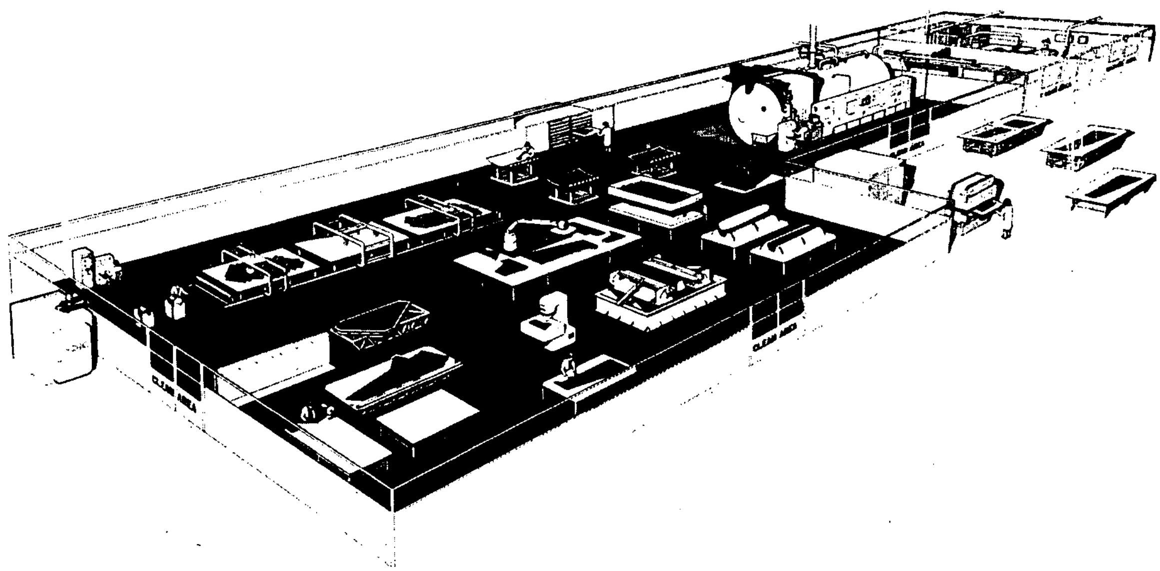

Figure 1. British Aerospace's proposed carbon fiber composite production facility would include automated layup, cutting, and bonding, and a microprocessor-controlled autoclave. 25X1

cross-linked. Most modern manufacturing techniques evolved using the tack of the resin to hold the plies together during handling and processing. Thermoplastics must be melted to stick to each other and to be consolidated into a single laminate. New methods must be developed to efficiently process thermoplastic composites into aircraft structures.

ICI is conducting processing research with filament winding, tape laying, hydroforming, and roll forming, as well as encouraging research by private companies and universities. Westland Helicopter is presently working on forming techniques for thermoplastic composites by developing a tailplane section from PEEK/carbon. Besides gathering design data, Westland is developing automated processing techniques. To form the tailplane skin surfaces, a hydroforming press is being used. Because the available press is small, a compression press is being used to form the larger components (> 0.5 meter). Westland is developing pressure cycles and automated load/unload mechanisms for the presses.

European Aircraft Program

BAe's latest endeavor in composite aircraft is the European Aircraft Program (EAP), which started as a multinational fighter design program in 1982, and which has developed into the European Fighter Aircraft (EFA) today. Originally MBB was supposed to build approximately 40 percent of the prototype and 25X1
to help with the design and construction of the composite components. The Germans pulled out of the effort fairly early because the French were not participating and the Germans did not want to fall into disfavor. MBB helped an estimated 4 percent in the final program. The main composite development fell to BAe. 25X1

BAe drew heavily from the work on the Jaguar composite wing and the development of the composite forward fuselage. The EAP wing—a single cobonded structure—uses composite for the spar box and the

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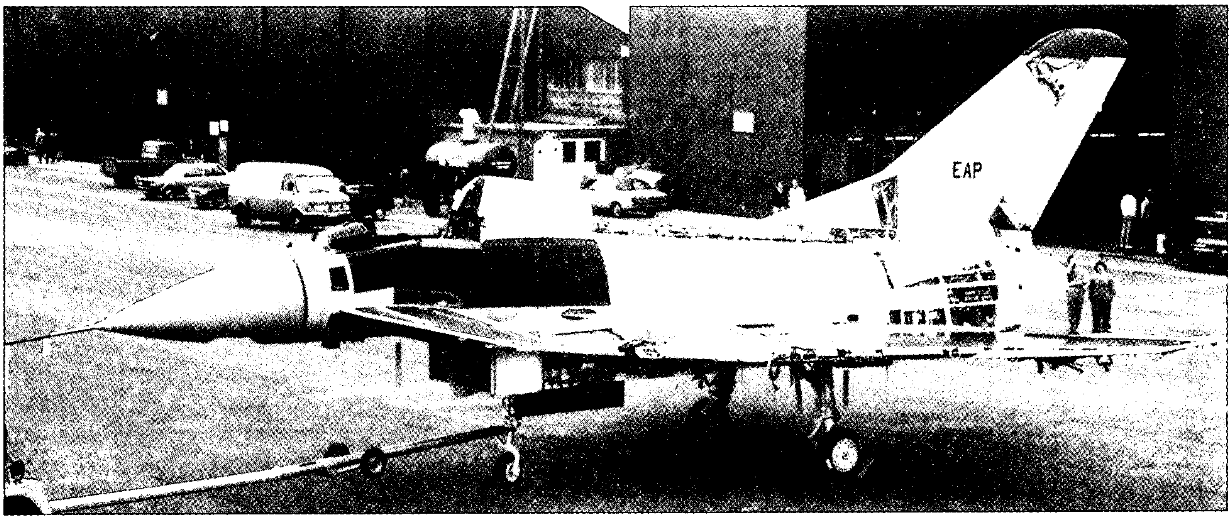

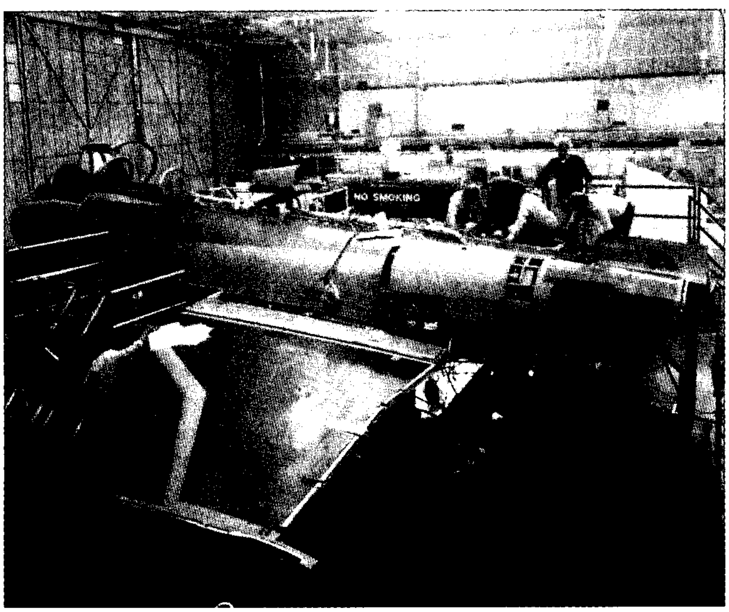

Figure 2. British Aerospace mates wings and fuselage of EAP demonstrator aircraft.

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wing skins. Metal forms the leading edges and slots for the flaps and ailerons. The cockpit uses composite for the internal structure and the fuselage skin. BAe used the Samlesbury facility to build the structures; therefore, tape laying was used along with water jet cutters. All composite materials are carbon/epoxy and were autoclave cured. The EAP was completed in 1986 and flew at the Farnborough show. This aircraft proves that BAe has developed much of the design and manufacturing capability needed to design a 50-percent composite fighter (see figure 2).

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West Germany

West Germany began researching composites structures early in the 1970s, like the United Kingdom, but the effort was generally smaller. The first use of composites was for helicopter rotors. MBB began building rotor test components with CF in 1970. The first major aircraft structure program was the joint BAe/MBB Tornado taileron program started in 1973. MBB both designed and built components for the taileron. At this point the work was being done by hand layup because of the small number of test parts. [redacted]

Automated Techniques

West German researchers recognized the importance of automated techniques and began development both in the university system and in corporate research centers. The West Germans were particularly interested in filament winding and tape laying. In the early 1970s, West Germany was the largest GRP producer in Europe, and filament-wound GRP products were well developed. Researchers at MBB and the Plastics Institute at Aachen began to wind CFRP components. It is important to note that in the early 1970s the West Germans were considered behind in fiber orientation technology and that by the mid-1980s many aerospace researchers considered the West Germans capable of producing some of the best winding equipment in the aerospace industry. [redacted]

According to technical papers, one of the most influential research groups in filament winding was at the Institute for Plastics Processing in Aachen. The leading researcher through the 1970s and the 1980s is Dr. Georg Menges. He and his students have continually produced excellent and novel research in filament winding, control variables, tape laying, robotics, and other composite automation techniques. [redacted]

Composites Processing

As in Britain, high CF prices, unknown failure characteristics, and budget constraints slowed the development of composites processing. The research programs did not provide enough volume to necessitate development of large-scale automated manufacturing equipment. This began to change in the late 1970s as two programs began to move to production. [redacted]

Dornier was experimenting with small composite components. When speed brakes made with CFRP were successfully tested on the Alpha jet, a decision was made to go into production. The Alpha brakes were made with carbon/epoxy skins and aluminum ribs that were attached to the ribs by metal rivets. Dr. Flemming of Dornier discussed continuing research and current production in a 1978 presentation at the West German Federal Academy of Defense. The main problem Dornier had was a lack of trained personnel to work with the composite materials. Other continuing projects included a rudder fin and a horizontal stabilizer. The rudder fin used CFRP skins 25X1
and metal ribs joined by metal fasteners. This type of construction of the horizontal stabilizer was not discussed. [redacted] 25X1

Further research at MBB shows the increasing commitment of the designers to large CFRP components. A 1979 design for an advanced tactical fighter concept named the TKF-90 (or TCA) called for a carbon composite wing, control surfaces, and some fuselage components. MBB began a development program in 1976 for composites use in the Airbus A300 and A310 aimed at reducing weight and costs. MBB was in charge of developing a composite rudder and vertical stabilizer that was part of a large program between the Airbus companies, which also studied the use of CFRP for spoilers, leading edges, doors, fairings, and control surfaces. Figure 3 shows the composites used 25X1
on the A300-600 version. [redacted] 25X1

The vertical fin was 27 feet high, 26 feet wide at the base, and 10 feet wide at the tip. MBB designed this structure to meet several objectives. The new structure had to reduce weight by 20 percent, be interchangeable with the A300 and A310, exhibit fail-safe characteristics, and have a service life of 48,000 flights. Manufacturing costs had to be at or below 25X1
equivalent metal manufacturing levels. [redacted] 25X1

The final design uses carbon/epoxy composite and honeycomb. The leading edge and torsion spar box use honeycomb covered with ±45- and 0-degree layers of prepreg fabric. The integral stiffeners in the

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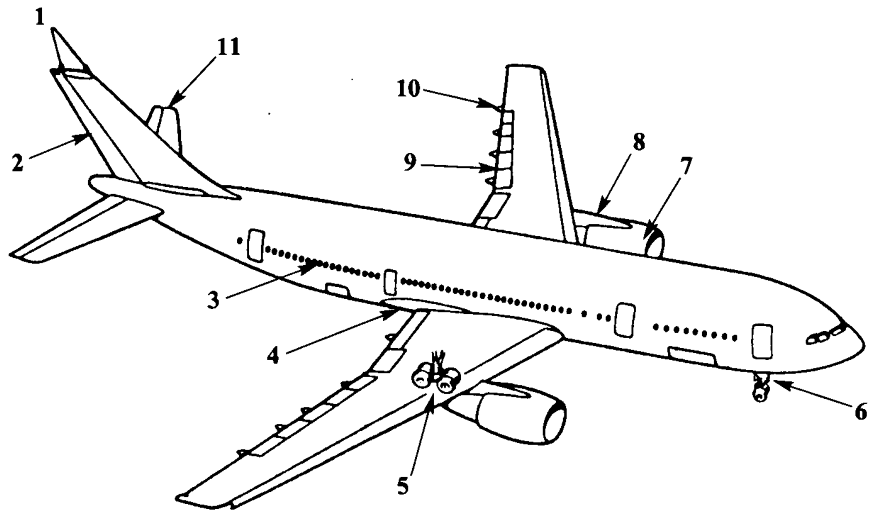

1. Tail fin: nose and back edges
2. Side rudder
3. Cabin floor bracing
4. Hollow groove for wing-fuselage transition
5. Main landing gear flaps
6. Nose landing gear flaps
7. Engine gondola components
8. Pylon lining
9. Braking flaps/spoilers
10. Flap mechanism lining
11. Elevator: tip and back edge

Figure 3. *Use of composite fiber elements in Airbus A300-600* 314348 9-87 25X1

fin eliminate the need for conventional ribs. Total parts in the design were reduced from 17,015 to 4,800, and in the spar box the number of parts was reduced from over 2,000 to 96. MBB met the weight savings goal of 20 percent and reduced costs by 10 percent; automation of production is expected to reduce costs by a total of 20 percent.

To meet production demands for the rudder as well as to prepare for future increased use of composites, MBB began developing an automated composites facility. In 1983, MBB was planning for material cutters, automated layup, and automated inspection stations. MBB converted the Stade factory into the composites center for rudder production. The first rudder units from this plant were completed in the spring of 1985. Up to 1985, MBB had invested just under 14 million deutsche marks (DM).

MBB is using its knowledge of composites to begin research into composite helicopter structures. Traditionally, helicopters have used composites extensively only in the rotors, but MBB wants to develop fuselage components using both thermoset and thermoplastic composites. The government is also interested and has provided some funding. The Ministry of Defense has contracted with MBB to build a partially composite airframe based on the BO-105 by early 1987. The design is conservative in order to control costs, but designers expect to save 20 percent or 110 to 132 pounds in weight.

Dornier has continued its use of composites in the DO-228 commuter plane. However, the technical level of expertise is well below that of MBB. The

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Dornier 228 uses only 10-percent composites in nonstructural components such as fairings, doors, and trailing edges. Dornier uses aramid and carbon fibers and Nomex honeycomb. Some parts, such as the landing gear fairing, use a hybrid composite structure of aramid and carbon fibers over Nomex (see figure 4). 25X1

Funding over the years for composites has come from both the government and private industry. On the MBB rudder program, the government invested substantially in the development of the design and fabrication facilities. From 1982 to 1984 alone, the German Government provided over 16 million DM. The government also supports research through the Ministry of Defense, the DFVLR, and university research funding. Specific funding is unknown. 25X1

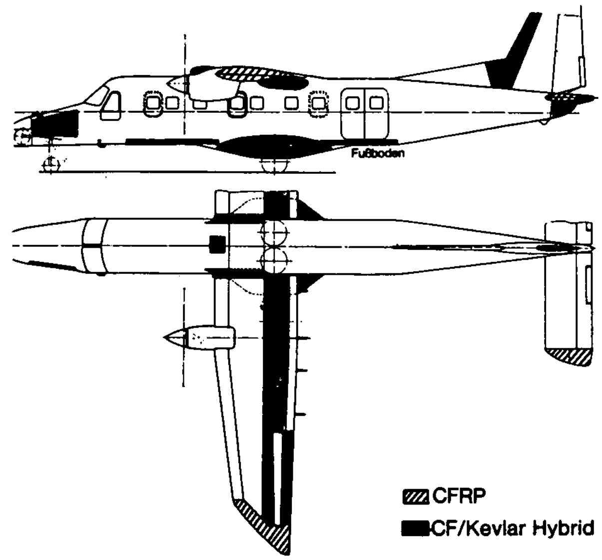

Figure 4. Distribution of different types of composites in the DO-228. 25X1

Research

In addition to the work of MBB and Dornier, the research being conducted at the universities is important. The Institute for Plastics Processing has already been mentioned, but several other universities are actively investigating composites. Programs exist at Darmstadt and Frankfurt, and a large polymer program is supported at Mainz. The research programs are not specifically geared to aircraft composites, but the students learn the basics needed to enter the field of aircraft composites.

The Darmstadt program is called the Deutsches Kunstoff Institut. In 1984 the institute had 25 scientists and engineers and 20 supporting staff with an estimated budget of 7 million DM. The institute at Aachen is officially called the Institut fur Kunstoffverarbeitung. The institute supported 65 professionals and 65 supporting staff in 1984. One-third of the budget is from the state (Nord Rheinpfalz), one-third from the federal government, and one-third from private industry.

Recent scientific research articles in the European press have been on various topics of interest to the aerospace industry. Researchers are investigating composite molds for the MBB rudder program, compression presses with short strokes designed specifically for composites processing, filament winding, robotic tape laying, photocuring prepreg materials, and numerical analysis of winding patterns for complex shapes. These same topics are being researched by the United States. 25X1

France

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There are two types of carbon fiber composites made in France of interest to the United States, CFRP and carbon/carbon (C/C). Both types of material have become recognized worldwide as important to the future of aerospace. 25X1

CFRP

France began developing CFRP similar to the way Germany did, but perhaps even slower. Carbon fibers were first used in helicopter blades by Aerospatiale. Like MBB and BAe, Aerospatiale experimented with small nonstructural parts in the early 1970s. Fillets, fairings, wheel wells, and other small elements were developed by hand. Some parts were developed later for the Concorde. 25X1

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Not until the late 1970s did French aerospace interests begin serious development of structural CFRP components. Aerospatiale developed a partially CFRP vertical stabilizer for the Mirage 2000 that was put into production in 1980-81. During the middle-to-late 1970s Dassault-Breguet was also investigating CFRP, but little is known of specific work. In 1978, Dassault and Aerospatiale agreed to collaborate on the development of a CFRP wing for the Falcon business jet. This project was a major design and manufacturing undertaking for both firms.

The Falcon wing program was designated the V10F airfoil program. The government provided funding for both companies, and both companies agreed to share data and knowledge gained. Dassault and Aerospatiale were each to build a wing, and the program was to culminate in a test flight in 1982.

The first wing skin panels were constructed in 1980. These panels were 6.5 meters long and 1.5 meters wide, with integral stiffeners. The entire panel was cured in a single operation. The final design called for the entire wing spar box to be made of cocured carbon/epoxy.

The V10F program was conducted by coordinators from both companies. The Dassault facility at Velizy was responsible for testing along with the Central Laboratory and Industrial Laboratory of Aerospatiale at Suresnes. Production techniques were developed at Aerospatiale's Nantes facility and Dassault's Biarritz plant.

During the six-year collaboration, researchers investigated all aspects of composites. Studies were conducted on the design of structural components, fatigue, and failure mechanisms. Computer simulations and design aids were programed and refined. Manufacturing techniques for cocuring large panels were developed along with nondestructive testing techniques. Tooling techniques were developed, and both firms were probably beginning to develop tape-laying techniques. The wing was designed using proven fibers and resins: T300 fibers, and CIBA 914 and NARMCO 5208 resins. The material systems were well tested in the aerospace industry and presented little risk.

The design and development were major steps forward for both companies, but the design was not that advanced compared with the United States' aerospace industry. The V10F wing was designed like a conventional metal wing. In the end, the wing spar box weighed 20 percent less than the equivalent metal wing, but more weight could have been saved if the designers had been able to design a more efficient wing. 25X1

Aerospatiale's composites work for the Airbus program was limited during the 1976-82 time frame. MBB's rudder program was by far the largest composite structure developed. The Nantes facility produced various parts for both the A300 and A310 that included fairings and Karman panels of aramid/epoxy and low-speed ailerons from carbon/epoxy. CFRP parts were also being produced for the ATR 42 and the Mirage 2000. CFRP ailerons, wing flaps, and trailing roots were built for the ATR 42, while the fin spar box and doors were built of CFRP for the Mirage 2000. 25X1

As production demands increased for all of these components, the Nantes facility became more and more automated. Computer-controlled autoclaves were installed to properly control the cure cycle. An 800-square-meter room was built to provide a dust-free, temperature- and moisture-controlled facility. Other equipment available includes a total immersion ultrasonic scanning unit for nondestructive testing and a five-axis milling center to cut the cured parts to final shape. The most interesting piece of machinery is the SIDACO system—a computer-controlled layup system developed by Aerospatiale that includes a water jet cutter to cut the composite cloth to size. The exact specifications of the machine are unknown. 25X1

Aerospatiale has continued its composite development with the ATR 72, a stretched version of the ATR 42. Aerospatiale has developed a CFRP outboard wing-box for the commercial transport. This development draws heavily from the V10F program and other primary structure research funded by the government.

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The wing box structure is very similar to that of the V10F. The box contains a 1,500-liter fuel tank and is integrally stiffened with carbon/epoxy spars and panels and light alloy ribs. The current production schedule calls for the first box to be completed by December 1987. [redacted]

Aerospatiale considers the development of an automated composites facility necessary for commercial survival. Plans call for the acquisition of an automated parts and tools handling system by 1987. Nantes committed 40 percent of the capital investments for 1986 to composites development. By 1987 there were 5,000 square meters of environmentally controlled assembly area, and plans call for 1987 delivery of another composite cloth draping or tape laying machine. Experiments are also being conducted with the firm MFL at a composite pilot workshop at Suresnes. The next development for Aerospatiale will most likely be a composite wing. [redacted]

Dassault also continued composites development after the V10F program. Dassault's next project was the development of the ACX aircraft commonly known as the Rafale. The Rafale uses carbon composite in the wing skins, spar, control surfaces, forward fuselage, and empennage. Aramid composite is used for the nose. Dassault launched the ACX program in 1983 and began prototype production in 1984 at the St. Cloud plant. The prototype first flew in the summer of 1986 (see figure 5). [redacted]

Specific production techniques are unknown, but are probably similar to those of Aerospatiale because of the close working relationship between the two companies on the V10F. Dassault must also be developing a composites facility in order to be competitive in the 1990s. [redacted]

The French have illustrated their commitment to advanced composites by acquisition as well as through internal research. In 1984 the heavy machinery company MFL purchased Goldsworthy Engineering, Inc. (GEI)—a US firm that has consistently led the aerospace community in the development of automated composites processing equipment. GEI currently produces filament winding, pultrusion, and tape-laying equipment that is considered of excellent quality in the aerospace industry. Dassault and Aerospatiale, both major stockholders in MFL, have ordered advanced two-phase tape-laying systems from GEI called Access/Atlas II. This sytem is called two-phase because in one operation it cuts the tape to be laid down and stores it on a cassette, and then lays the tape down in a separate operation. The Access system is the fastest in the world, with possible speeds of 1,200 feet per minute. [redacted] 25X1 25X1

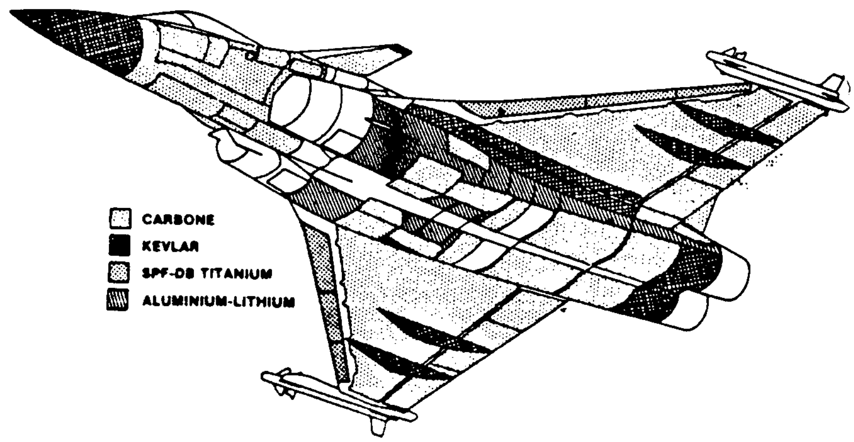
The French Government has supported composites development through information dissemination as well as through funding. In October 1983 the government founded the Composite Materials Institute in Bordeaux in order to facilitate technology transfer between small and medium-sized companies and the established composites producers and also to emphasize and encourage standardization. The institute is organized as an association including Dassault, Aerospatiale, AEC, the European Propellant Company (SEP), Elf, and Bordeaux University. The organization received an initial subsidy of 2 million French francs (FFr) from the French Government. Before the establishment of the institute, most composites knowledge was kept within the large companies doing the research. The institute should make development easier and should provide France with a broader base of composite research and development. [redacted] 25X1 25X1

Carbon/Carbon

Aerospatiale was the first French firm to study C/C in 1968. Subsequently, Aerospatiale worked with another company called Le Carbone Lorraine to develop C/C applications. In 1975 the two companies formed a C/C producer called Aerolor. This company continued to research C/C as well as to begin producing components. [redacted] 25X1 25X1 25X1

The European Propellant Company also began development of C/C in the early 1970s. SEP developed a material that was marketed as Sepcarb, first tested in 1973. SEP has continued to develop C/C manufacturing methods and applications. [redacted] 25X1

Figure 5. Composites used in the Rafale. 25X1



C/C composites are made by weaving carbon fibers together into the near-finished shape called a preform. This preform is saturated with a matrix phase of either pitch, vapor-deposited carbon, or a pyrolizable resin; then the preform is heated to carbonize the matrix phase. This process is repeated until the desired density and porosity are attained. The most difficult parts of the process are the fiber alignment during weaving and quality control during densification. Different methods of weaving composite have been developed by both SEP and Aerospatiale.

The main use of C/C is for rocket nozzles and nose cones. SEP is in charge, through G2P, of the solid propulsion for the strategic and tactical missiles of the French Deterrent Force. G2P is a joint venture between SEP (75 percent) and SNPE (25 percent). SEP produces rocket motor nozzles for the three-stage submarine-launched M4, the Pluton semiballistic missile, and the tactical missiles Super 530D, DURANDAL, and SATCP. SEP also produces apogee motors for the MAGE 1S and MAGE 2. Aerolor produces rocket motor nozzles, but specific uses are unknown.

Reinforcement architectures for C/C can be broken down into three categories: 4-Ds, 3-D weaves, and braided. 4-D assemblies consist of rigid rods stacked in a hexagonal planar or pyramidal array with axial rods at the intersections. 4-D is a low-cost approach that provides rapid layup with minimal tooling and rapid densification. SEP uses the pyramidal 4-D architecture. Aerospatiale uses 3-D weaving techniques. Weaving requires the largest investment in automated equipment. Billets can be rapidly fabricated in cylindrical and conical forms and are then machined to the final contour. Braiding is a relatively immature technique being studied. Researchers in the United States believe superior properties can be obtained using through-the-thickness braiding as compared with weaving and 4-D techniques (see figure 6). 25X1

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C/C composites are being increasingly used for brakes in the aerospace industry. Sepcarb material is used by Messier-Hispano-Bugatti (MHB) for Mirage 2000 brakes, A300 and A310 brakes, and Falcon 900 brakes. Aerolor is also investigating the use of C/C for brakes. C/C brakes are used in racing cars and have been suggested for high-speed trains. Currently, they are more expensive than standard brakes, but prices are expected to come down, and the weight savings to lead to lower fuel costs and increased 25X1

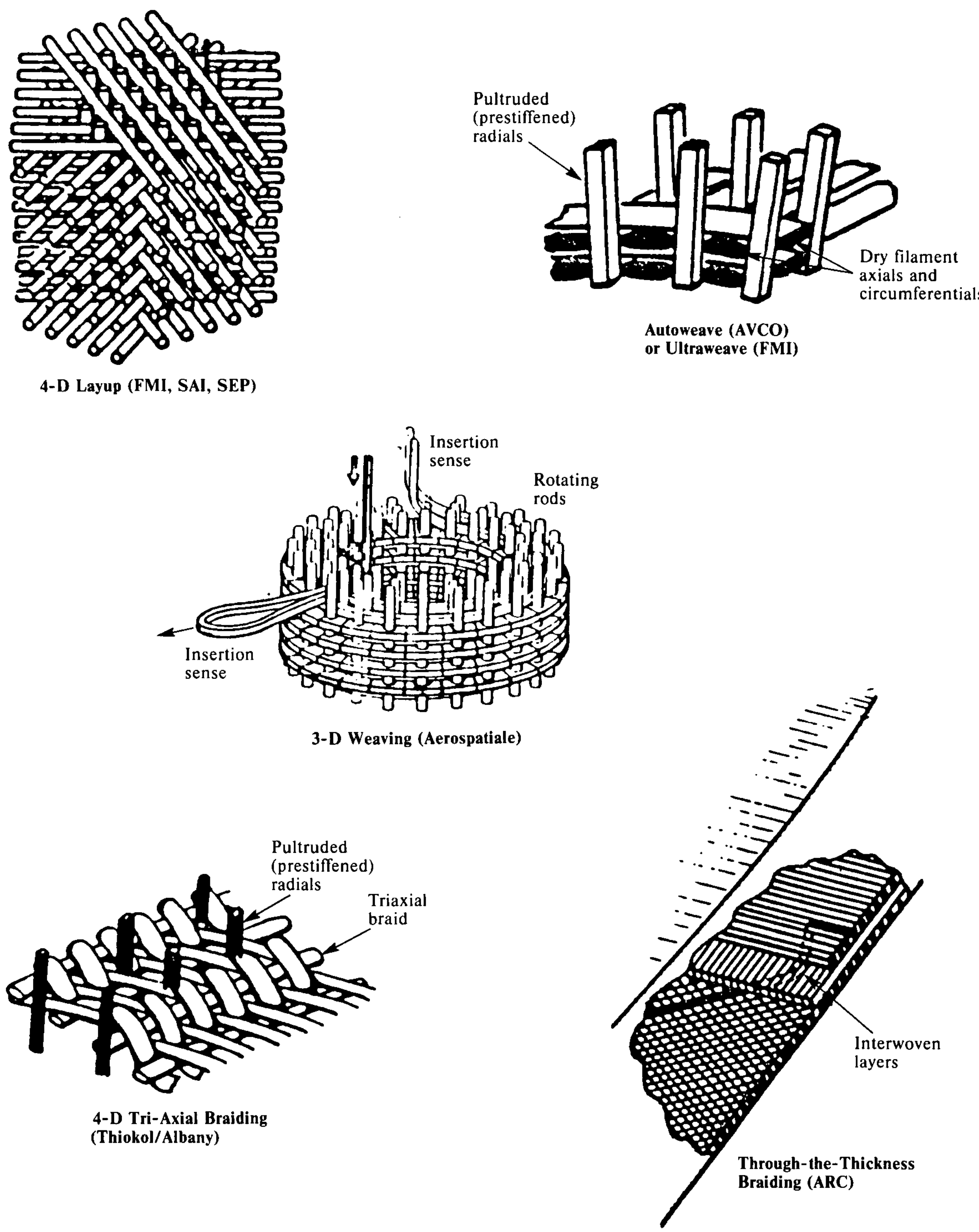

Figure 6. Comparison of thickness braiding, weaving, and 4-D techniques.

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payloads for aircraft. C/C brakes reduced weight by 450 kilogram on the A300. MHB claims its brakes absorb 600 kilojoule per kilogram, or about twice as much energy per kilogram as conventional brakes.

SEP is expanding in the C/C market with a joint venture. In 1985, Alsthom Atlantique teamed with SEP to form Carbone-Industrie. Initial capital for the firm was 40 million FFr. The new group will compete with US C/C brake manufacturers on the international market. SEP C/C production was 15 metric tons in 1985, worth 30 million FFr. Production is expected to reach 60 tons by 1990.

Other Countries

Several other companies in various West European countries currently make composite structures for aircraft, but their technical level is well below that of the major producers. The most prominent of the smaller companies are Fokker in West Germany, CASA in Spain, Aeritalia in Italy, and Saab in Sweden.

Fokker makes CFRP parts—including floor panels, fairings, and doors—for its line of transports. CASA produces components for the A300 and A310, but the technology for the design and production comes from the other partners in the Airbus consortium. Aeritalia and Saab are developing a larger composites capability.

Aeritalia has used technology developed by Boeing, BAe, and Aerospatiale to construct a first-rate composites production facility that produces parts for Boeing 7-7 aircraft, the ATR 42, and ATR 72, and has produced parts for the EAP prototype. From this technology base, Aeritalia could develop into a major composites producer.

Saab has worked with composites on small parts since the mid-1970s. Currently, the company is using technology furnished by BAe in order to develop composite wings for the Grippen aircraft. Saab could also develop from this technology base into a major composites producer.

Outlook

We believe that by 1995 the major aerospace firms will be able to build a small fighter-type aircraft with roughly 60-percent composites. The wings, forward fuselage, empennage, and vertical and horizontal tails will all be composite structures. Automated tape laying, filament winding, computer-controlled material handling systems, and computer-controlled autoclaves will be combined into an automated production facility. Manufacturers will be developing mostly composite commercial transports. Most of the wing structure on the large aircraft will be composite as will be the horizontal and vertical tail assemblies. Composite fuselage sections will be at the test stage. The common material will still be carbon/epoxy, but some thermoplastic parts will be well developed.

The European practice of multinational consortiums, such as Airbus, will continue. This practice promotes dialogue and exchange of technologies and serves to raise the technological level of all participating companies. The large technology base fostered by these ventures will also provide continued strong competition for US manufacturers in commercial and military aircraft.

In the area of C/C composites, the United States leads the French, but the French have a solid production and research foundation from which to expand. The French Government will continue to support development both for internal strategic reasons and to exploit a technology lead over the other European countries. US manufacturers will continue to lead in production technology assuming there is continued research and development in new technologies such as braiding. In areas where the more advanced forms of C/C composites are not needed, the French will provide stiff competition. In the face of increasing French production capability, US manufacturers will find it harder to sell to European customers such as Airbus. [redacted] 25X1

Education in composites at the university level has been increasing in Europe as it has in the United States. This trend will continue as more and more trained personnel are needed to fill the increasing market in aerospace composites. University research is strong and well supported both by industry and the federal governments. Funding for both research and education will grow slightly as advanced composites are used more in aerospace, automobiles, and construction. [redacted] 25X1

Glossary of Terms

Composite
Any material that is a combination of continuous fibers and some matrix material. The fibers provide strength while the matrix holds the fibers in place and protects them. The fibers may be carbon or aramid. The matrix may be a polymer resin or amorphous carbon.

CFRP (carbon fiber reinforced plastic)
Any composite that uses carbon fibers in a plastic resin matrix. The resin may be either a thermoset or a thermoplastic polymer.

C/C (carbon/carbon)
A composite made from carbon fibers in a carbon matrix. The carbon fibers are woven into some shape and then infiltrated with a carbon-based matrix material such as oil pitch. The matrix is carbonized into pure carbon by pyrolizing the structure at high temperatures; that is, over 2,000° Centigrade.

Cobonded structure
Process of forming a composite structure by laying all the parts up together and curing them all at once. The process has the advantage of using only one cure cycle and providing a high-strength structure without fasteners.

PEEK (poly ether ether ketone)
A thermoplastic resin being researched for aerospace composites because of its toughness and high melting point.

Thermoplastic
Any resin in which the molecules do not form chemical bonds when heated, and therefore can be melted and formed repeatedly. Molecules may form crystals or remain amorphous.

Thermoset
Any resin in which the molecules form chemical bonds between each other when heated to the cure temperature. Once the resin is cured, the form of the resin cannot be altered without breaking the chemical bonds. Epoxies are thermoset resins commonly in use today.

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